Hubble Space Telescope Bi-Stem Thermal Shield Analyses

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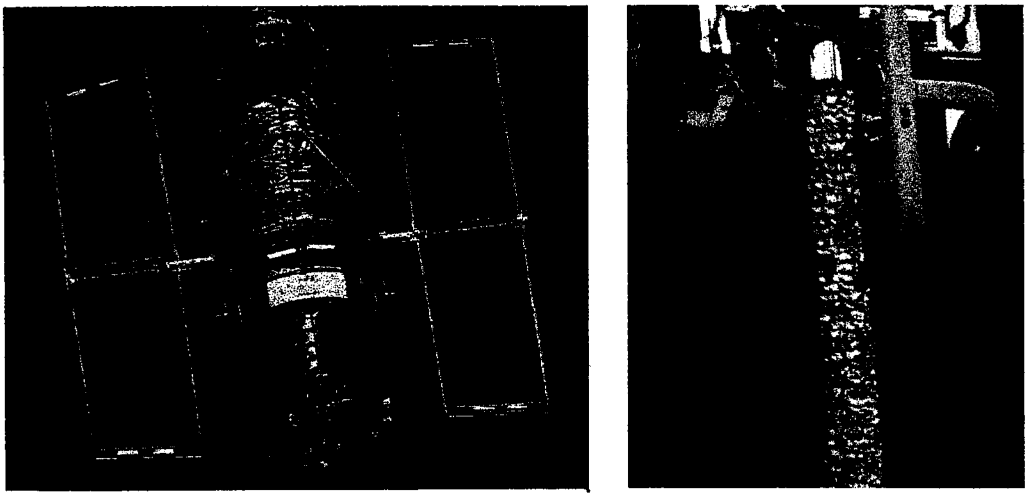
The Hubble Space Telescope (HST) was launched April 24, 1990, and was deployed April 25 into low Earth orbit (LEO). It was soon discovered that the metal poles holding the solar arrays were expanding and contracting as the telescope orbited the Earth passing between the sunlight and the Earth's shadow. The expansion and contraction, although very small, was enough to cause the telescope to shake because of thermal-induced jitters, a detrimental effect when trying to take pictures millions of miles away. Therefore, the European Space Agency (ESA, the provider of the solar arrays) built new solar arrays (SA-II) that contained bi-stem thermal shields which insulated the solar array metal poles. These thermal shields were made of 2 mil thick aluminized-Teflon fluorinated ethylene propylene (FEP) rings fused together into a circular bellows shape. The new solar arrays were put on the HST during an extravehicular activity (EVA), also called an astronaut space walk, during the first servicing mission (SM1) in December 1993. An on-orbit photograph of the HST with the SA-II, and a close up of the bellows-like structure of the thermal shields is provided in Figure 1.

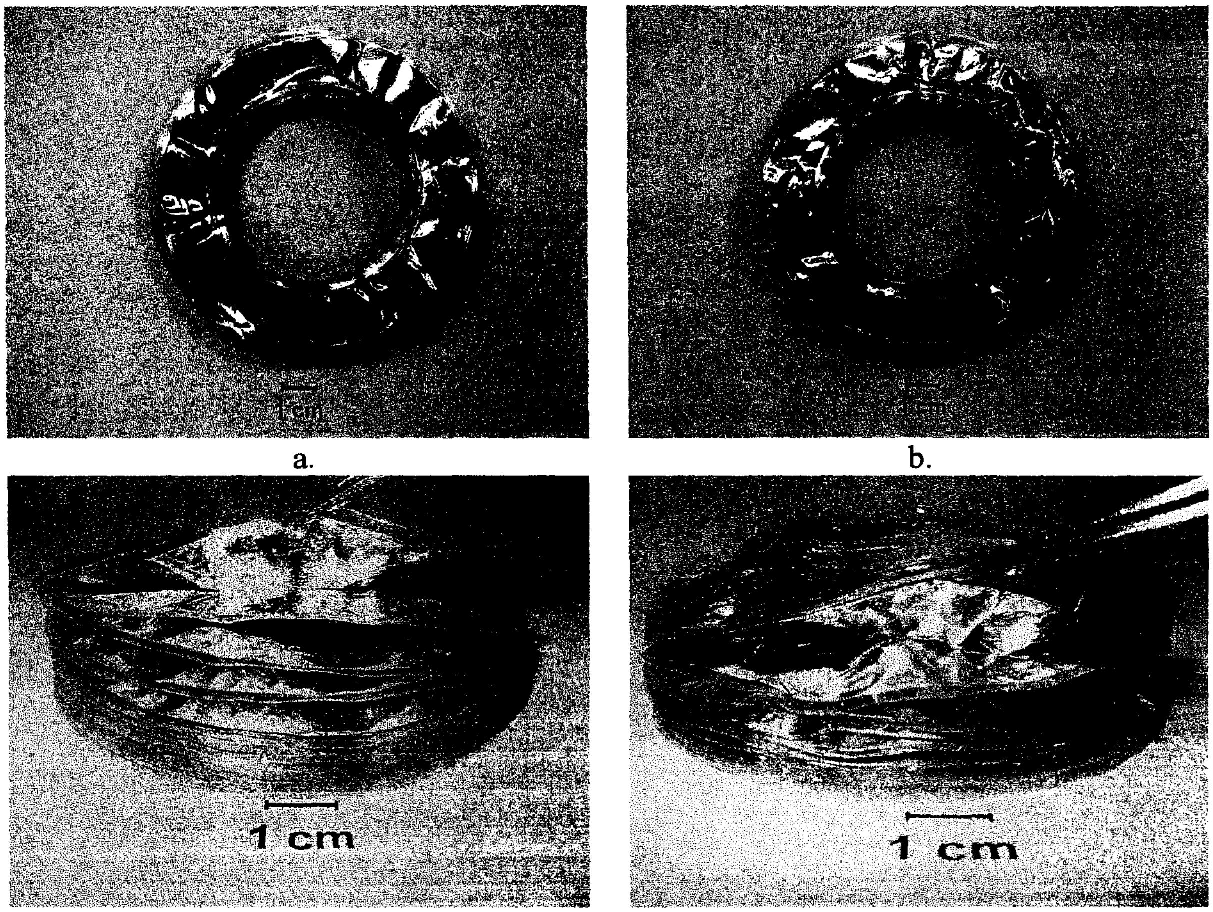


a b.

Figure 1. On-orbit photograph of the Hubble Space Telescope during SM1, a). HST with Solar Array II attached, and b). Close-up of a section of thermal shields.

While in space the bi-stem thermal shields were exposed to space phenomena such as atomic oxygen, ultraviolet (UV) radiation and electron and proton radiation (Van Allen Belt trapped particle radiation), in additional to thermal cycling and vacuum. On Earth, oxygen is a diatomic molecule, but in LEO short wavelength UV radiation breaks the diatomic bonds and forms monatomic oxygen, which is highly reactive. Therefore, when it collides with the FEP in space it will react, and can chemically erode it away, while the UV and particle radiation embrittles it. This is problematic when using the material as a long-term insulator, because it turns the FEP from a flexible and stretchy substance into a hard brittle substance, causing it to crack and break apart, losing its effectiveness as an insulator, affecting the durability of satellite systems.

After 8.25 years in space, during the fourth servicing mission (SM3B) in March 2002, the second set of solar arrays were retrieved and replaced with a third set of arrays (SA-III). A section of the bi-stem thermal shields was provided to the NASA Glenn Research Center from ESA, so that the environmental durability of the thermal shields could be studied and compared to previously retrieved and studied insulation materials from HST. Figure 2 shows images of the as-retrieved bi-stem sample.



a. b.

c. d.

Figure 2. Post-retrieval images of the thermal shield sample provided to Glenn: a). Side A, b). Side B, c). Anti-solar side lifted to show individual welds with no cracks, and d). Solar facing side lifted to show individual welds with through-thickness cracks.

As can be seen in the pictures, the retrieved sample is severely damaged on the solar exposed side (image 2d and right side of images in 2a and 2b). It was more severely damaged than it was originally thought to be, compromising the original plans of how some tests were to be performed. Instead of laying flat as well as being reflective, the bi-stem thermal shield puckers on the solar-facing side and contains through-thickness cracks and has pieces flaking off. Between the fused rings, or welds, the solar-facing side is no longer continuously connected, and large holes and cracks reaching from the inner weld to the outer weld exist. Images at low magnification of cracks and holes taken with an Olympus Stereo Zoom microscope are provided in Figure 3.

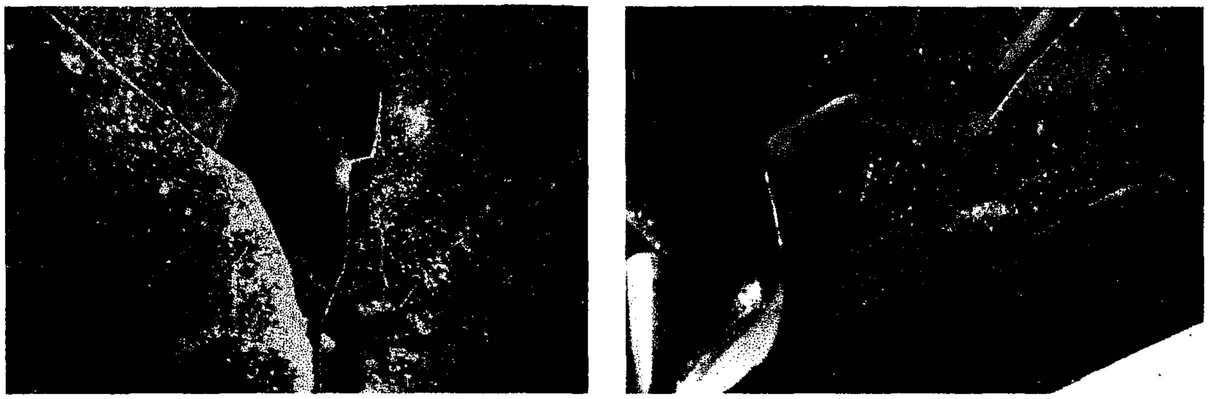


Figure 3. Optical microscopy images of the thermal shield sample section "Weld 3": a). Hole in weld, and b). Through-thickness cracks.

Four tests are to be completed on both pristine material, to provide a control and reference to how degraded the material is, and the space-exposed material. The first of these are tensile tests. A 38.5 cm long dog-bone shaped piece of material, with 2.5 cm in the narrowest area, is cut and then stretched by a machine until the piece breaks. Results between the pristine and space-exposed materials can then be compared as to whether changes in the mechanical properties have occurred. Large differences between the pristine and space-exposed material are expected in the ultimate tensile strength and elongation at failure. Unfortunately due to the extensive damage on the solar-facing side of the space exposed material, a dog-bone sample appears to be impossible to cut, and so a tensile test will not be completed on the solar facing side. An attempt at getting a piece as close to the solar-facing side as possible will be done, to try to get an idea of the decrease in elongation at failure.

The optical properties of the bi-stem thermal shield will also be examined. The solar absorptance and thermal emittance are to be measured on both the pristine and space-exposed material and it is not expected that the optical properties will be greatly changed. To test these properties, a keystone shape will be cut out around a ring of both the pristine and solar-exposed material and using a Lambda-19 UV/VIS/NIR Spectrophotometer the reflectance will be measured. In the damaged area of the solar exposed material, a piece as close to the size needed will be cut.

Density and hardness tests will also be completed. To measure the nano-hardness of the material, a small, approximately 0.8 x 0.8 cm square is mounted on three Atomic Force Microscope holders. It is then placed inside of a nanomechanical system that is operated in conjunction with an Atomic Force Microscope and is able to provide ultra light load indentations and can continuously measure force and displacement as an indent is made. Hardness vs. contact depth measurements are made and graphed. Preliminary tests on pristine FEP have been conducted to evaluate creep during the indentation process. It is important to unload the indenter after creep has stopped. The tests conducted indicated that a 15 second hold period is needed to minimize creep. Figure 4 shows the creep tests conducted at 500 μN loading for 5 mil pristine

Al-FEP. The deeper the indent the softer the material; and so by comparing the indent depths and computing the hardness from the indentation area the amount of embrittlement due to UV radiation can be quantified.

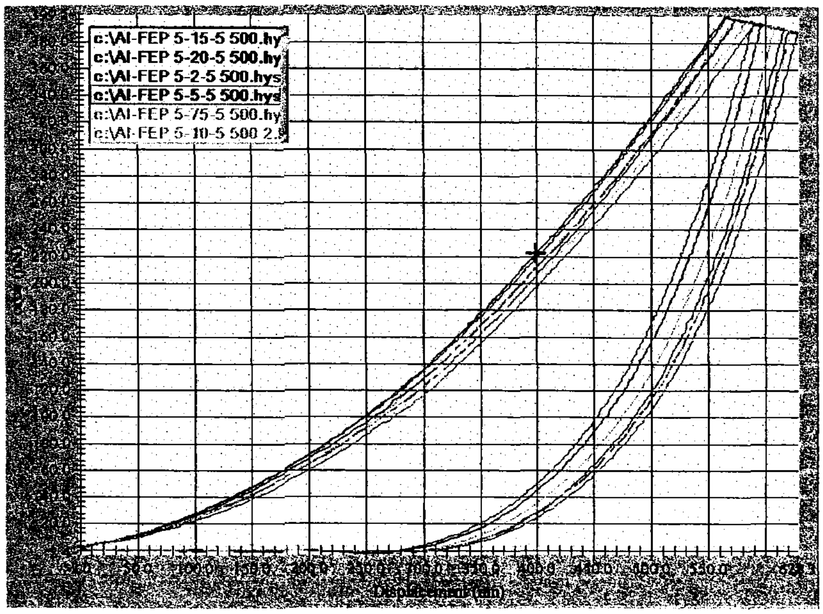


Figure 4. Nanomechanical indentation creep test data for pristine 5 mil thick Al-FEP.

Initial sample sectioning and documentation has been initiated, along with preliminary hardness testing. Tensile, optical, hardness & density tests are all planned. I hope to show the severe degradation of the space exposed Al-FEP bi-stem thermal shield throughout the testing process, and contribute to the continued research to improve materials used for space flight insulation. This information is crucial to the space community.